Assessment of the radiological impact and associated risk to non-human biota from routine liquid discharges of the Belgian nuclear power plants

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Abstract. We performed an environmental risk assessment (ERA) to evaluate the impact on non-human biota from liquid radioactive effluents discharged by the Belgian Nuclear Power Plants (NPP) of Doel and Tihange. For both sites, information on the source term and non human biota is provided where upon the selection of reference organisms and the general approach taken for the ERA is based. A deterministic risk assessment for aquatic and terrestrial ecosystems was performed using the ERICA tool and applying the ERICA screening value of 10 µGy h^{-1}. ERA was performed for the radioactive discharge limits and for the actual releases (maxima and averages over last 10 years 1999-2008). All ERICA reference organisms were considered and depending on the assessment situation, additional reference organisms were included in the analysis. It can be concluded that the current discharge limits for the Belgian NPP do not result in significant risks to the aquatic and terrestrial environment and that the actual discharges, which are a fraction of the release limits, are unlikely to harm the environment.

1. INTRODUCTION

The need for investigating potential risks induced by contaminants on non-human biota and ecosystems is now internationally recognized [1-4]. Recommendations and guidelines on international level and a comprehensive system to protect the environment from ionizing radiation are under development. As a consequence, a number of approaches/tools to estimate dose rates to non-human biota have been developed and some of them are being used in a regulatory context [5-6]. Initially, risk assessment focused exclusively on human health protection. Slowly, the demand for ecological risk assessment (ERA) has extended to non-human biota. As a consequence, ERA as a science has undergone considerable development in the last decades with guidelines being developed [7-8].

In view of the international changes regarding protection of non-human biota and possible future changes in national regulations, SCK•CEN was asked

by Suez-Electrabel to assess the exposure and associated environmental risk to non-human biota from routine radioactive releases from the Belgian Nuclear Power Plants. Fission and activation products released from nuclear power generating stations may be discharged into air or water. The study assesses the impact from radioactive liquid discharges (chemical component not studied) released in the river Scheldt at Doel and the river Meuse at Tihange on the present freshwater ecosystems and adjacent terrestrial ecosystems. The aim of this study is to evaluate if the limits established to protect humans are restrictive enough to also protect the environment and if actual aquatic discharges do not hamper the environment.

2. APPROACH

2.1 Problem formulation

The first stage of any ERA is the problem formulation, which deals amongst others with the characterisation of the contaminant source term and the identification of potential ecological targets and the associated exposure pathways.

There are two NPP sites in Belgium, each with a capacity of ~3000 MWe: the Tihange NPP discharges to the Meuse and the Doel NPP to the Scheldt. The source term was defined based on discharge limits and annual discharge data (1999-2008). Discharge limits for Tihange and Doel are given in Table 1. Since we require radionuclide specific concentrations for the evaluation of the environmental effects, we assumed for the Tihange discharge limits that all alpha activity consisted of ^{241}Am, which is among the most penalising alpha isotopes given its high dose conversion coefficient (DCC). ^{110m}Ag is to resemble all 'Other Radionuclides' because it shows a high DCC and high biota transfer. For the NPP at Doel, annual liquid discharge limits are specified for tritium (1.036E8 MBq y^{-1}) and unspecified α, β and γ release (1.48E6 MBq y^{-1}). We assumed the same repartitioning as for Tihange in beta-gamma emitters and alpha-emitters. Only ^{95}Nb which is not detected in actual discharges of Doel (see Table 2), was replaced by ^{58}Co.

Table 1. Annual liquid discharge limits in Tihange and Doel (MBq y^{-1})

	Tritium	**Beta and gamma**							**Alpha**
Tihange	^{3}H	^{60}Co	^{89}Sr	^{90}Sr	^{95}Nb	^{134}Cs	^{137}Cs	Others(^{110m}Ag)	(^{241}Am)
	1.48 E08	2.22 E05	2.78E03 [(1)]	2.78E 03 [(1)]	1.11 E05	1.11 E05	1.11 E05	3.27E05	2.22E 03
Doel[(2)]	^{3}H	^{60}Co	^{89}Sr	^{90}Sr	^{58}Co	^{134}Cs	^{137}Cs	Others(^{110m}Ag)	(^{241}Am)
	1.04 E08	3.69 E05	4.6E03	4.6E0 3	1.85 E05	1.85 E05	1.85 E05	5.44E 05	3.70E 03

[(1)] The annual liquid discharge limit for ^{89}Sr and ^{90}Sr together is 5550 MBq y^{-1}, assumed to be divided equally between the two radionuclides. Discharge of 'Others' assumed equal to discharge of ^{110m}Ag and alpha discharge to equal ^{241}Am. [(2)] The radionuclide-specified discharges are obtained by extrapolation of the portion of these radionuclides in the annual liquid discharge limits for Tihange. For more information, see [9].

Many radionuclides were monitored in the liquid discharges but only for a number relevant discharges (though therefore not each year) were obtained. For Tihange, these were ^{55}Fe ^{60}Co, ^{95}Nb, ^{134}Cs, ^{137}Cs, ^{89}Sr, ^{90}Sr, ^{3}H and 'Other Radionuclides' consisted of ^{58}Co, ^{110m}Ag, ^{123m}Te, ^{124}Sb and ^{125}Sb (for details see [9]). For Doel dose and risk assessment was performed for ^{51}Cr, ^{54}Mn, ^{58}Co, ^{60}Co, ^{95}Zr, ^{110m}Ag, ^{123m}Te, ^{124}Sb, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{89}Sr, ^{90}Sr and ^{3}H.

Table 2. Annual actual discharges for Tihange and Doel (MBq y^{-1})

Tihange	^{3}H	^{134}Cs	^{137}Cs	^{55}Fe	^{60}Co	^{89}Sr	^{90}Sr	^{95}Nb	Others
Average	4.7 E7	6.4 E2	9.7 E2	5.0 E3	6.1 E3	3.9 E1	1.9 E1	3.4 E2	1.5 E4
Maximum	6.7 E7	2.1 E3	2.1 E3	8.5 E3	1.0 E4	8.4 E1	4.2 E1	7.5 E2	2.7 E4

Doel	^{3}H	^{110m}Ag	^{58}Co	^{60}Co	^{51}Cr	^{134}Cs	^{137}Cs	^{54}Mn	^{95}Nb	^{106}Ru	^{124}Sb	^{125}Sb	^{89}Sr	^{90}Sr	^{123m}Te	^{95}Zr
Average	4.0E7	3.9E2	2.1E3	7.7E2	3.0E1	4.6E2	2.5E3	1.5E1	1.9E1	1.8E1	6.2E2	1.6E3	1.0E1	3.6E1	1.2E2	2.9E0
Maximum	5.4E7	1.3E3	9.3E3	2.4E3	7.0E1	3.5E3	9.4E3	7.4E1	8.9E1	1.2E2	2.3E3	2.5E3	8.4E1	1.87E2	3.8E2	2.2E1

The ecosystems to be evaluated were identified and reference organisms were indicated (Table 3). For the Tihange NPP, important terrestrial natural reserves may only be indirectly impacted by the discharges since the Meuse River is canalised down-stream the Tihange NPP. Only through the unlikely event extreme floodings or when placing dredged contaminated sediments on the river borders the natural reserve can be potentially impacted. For Doel the pristine natural reserve 'Verdronken Land van Saeftinghe', breeding ground for many birds and 'children's room' for fish and shrimp, and located in the tide zone of the Scheldt river, is potentially directly impacted. The characteristics of the reference organisms (habitat, life cycle, geometry, occupation factor) were determined.

Table 3. Selected reference organisms for the terrestrial and aquatic ecosystems near the Tihange and Doel NPP. Reference organisms written in italic are newly defined reference organisms. If reference organisms are underlined they are only considered for the Doel NPP assessment.

Reference Organisms - Terrestrial Ecosystem	**Reference Organisms - Aquatic Ecosystem**
Soil Invertebrate (ICRP Earthworm)	Phytoplankton (FASSET Phytoplankton)
Detritivorous invertebrate (FASSET Woodlouse)	*Phytoplankton (Cyanophycea)*
Gastropod (ICRP Snail)	Vascular plant (FASSET Vascular plant)
Amphibian (ICRP Frog)	Zooplankton (FASSET Zooplankton)
Reptile (FASSET Snake)	Insect larvae (FASSET Insect larvae)
Flying insects (ICRP Bee)	Amphibian (ICRP Frog)
Lichen & bryophytes (ICRP Bryophite)	*Pelagic invertebrate (e.g. Mysidacea)*
Grasses & Herbs (ICRP Wild grass)	Bivalve mollusc (FASSET Bivalve mollusc)
Grass roots	Gastropod (FASSET Gastropod)
Tree (ICRP Pine tree)	Crustacean (FASSET Crustacean)
Shrub/large grasses and herbs	Benthic* fish (FASSET Benthic fish)
Mammal (ICRP Rat)	*Benthic fish – small (e.g. common goby)*
Mammal (Rabbit)	*Benthic fish - large (e.g. European bass)*
Mammal (Small mouse)	Pelagic fish (ICRP Salmonid/Trout)
Mammal (ICRP Deer)	*Pelagic fish – small (e.g. Ninespich stickleback)*
Bird (ICRP Duck)	*Pelagic fish - large (e.g. Atlantic salmon)*
Large bird (e.g. Greylag goose)	*Salmonid egg (fish egg)*
Small bird (e.g. Meadow pipit)	Bird (ICRP Duck)
Bird egg (ICRP Duck egg)	*Large bird (e.g. Great Cormorant)*
Bird egg (Small)	*Small bird (e.g. Sedge warbler)*

2.2. Exposure and risk assessment

Concentrations in water and sediments were predicted based on the discharged amounts, river and radionuclide characteristics using the Schaeffer river model [10]. The maximum sediment concentrations, obtained for each radionuclide at a different distance of the discharge point, were calculated and organisms are conservatively assumed to be exposed simultaneously to these maxima.

Terrestrial organisms were considered being exposed to concentration maxima in dredged sediments disposed on the river banks.

To estimate the exposure to non-human biota, the EC-ERICA-Tool was used [11] and, with the exception of the solid-liquid distribution coefficients, the default parameter values were used to calculate the transfer of the radionuclides from sediment to organism. For the solid-liquid distribution coefficients, values more appropriate for the slightly alkaline conditions of the Meuse and Scheldt River were selected. No concentration ratios (CR) were available for Cr and Fe in the ERICA tool and these values were derived from literature or via similar approaches to derive CR estimates as proposed by Beresford et al. [12]. For the newly defined reference organisms, CR values were mainly derived from homologous reference organism.

To evaluate the potential impact of the liquid discharges on the ecosystem, the dose rates obtained for the reference organisms was compared with the screening value of 10 µGy h^{-1}, assumed to protect ecosystems as stated by ERICA [11] and PROTECT [13]. . Potential impact is expressed as a risk quotient (RQ), defined as the ratio of the dose rate and the screening value. If RQ < 1, the environment is unlikely at risk.

3. RESULTS AND DISCUSSION

In a first environmental impact scenario, the liquid discharge limits based on human protection criteria are used to check if these limits are set restrictive enough to also protect the environment. This scenario is a hypothetical scenario since the actual radioactive releases are much lower than the discharge limits. For all risk assessments (Tihange and Doel, aquatic and terrestrial environment) the RQs were below one (Figure 1).

For the freshwater ecosystem at Tihange, the highest RQ value (0.085) was obtained for 'Insect larvae' (Figure 1A). Since for all radionuclides the maximum sediment concentrations (although maxima occurred for the different radionuclides at different distances from the discharge point) were used in the assessment, it can be concluded with confidence that freshwater ecosystems will not be impacted if liquid discharges set at the current discharge limits would be released to the environment. Also for terrestrial ecosystems, all RQs are far below 1 (highest value is 0.069 for 'Rat', Figure 1B). ^{60}Co is the most contributing radionuclide for both ecosystems. Similarly, since it was assumed that terrestrial organisms are exposed to dredged sediments at their concentration maxima, disposed on the river banks, it can be concluded with confidence that the terrestrial environment will not be impacted if liquid discharges set at the current discharge limits would be released to the environment.

Also for freshwater ecosystems at Doel hypothetically impacted by the current liquid discharge limits, RQ is lower than 1 for all organisms. Highest RQ were obtained for phytoplankton and cyanophyceae (RQ=0.2). The radiological risk is almost entirely due to ^{241}Am. The ^{241}Am CR (40000 kg L^{-1}) for phytoplankton (and for the cyanophyceae a similar value was taken) is the highest among the reference organisms selected (factor 2 higher compared to insect larvae to a factor of 20000 higher compared to birds and pelagic fish). The origin of this CR [5] is a default R&D-128 value, of which the origin is ambiguous. Perhaps this CR is overestimated. Furthermore, the discharge limits for the Doel NPP are only set for tritium and other 'alpha, beta and gamma' activity, without specifying the amounts of the different discharged radionuclides necessary to assess the dose rates to non-human biota. Generally

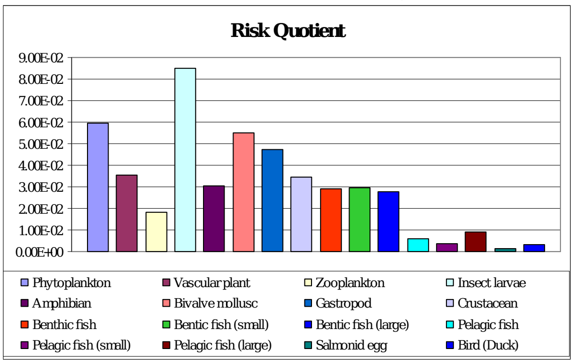
for 'alpha, beta and gamma' activity, a repartitioning between the different radionuclides was derived from the isotopic composition for the Tihange NPP discharge limits. Hereby, it was assumed that all alpha activity was composed of ^{241}Am. This is a conservative assumption given that the dose conversion coefficients (DCC) for ^{241}Am are among the highest. Discharges will unlikely contain ^{241}Am since discharges monitored over a 10 year period did not reveal the presence of ^{241}Am (or any other alpha emitter). We may hence decide that radiological releases at the liquid discharge limits will unlikely have a negative impact on the aquatic ecosystems of the river Scheldt. For terrestrial ecosystems potentially impacted by the release limits of the Doel NPP, the highest RQ (0.16, ^{137}Cs most contributing) was obtained for 'Rat' (Figure 1D).

Based on these results, it can be concluded that the liquid radiological discharge limits for the Belgian NPP are set at a level that no harm to the aquatic and terrestrial environment of Meuse and Scheldt is expected.

In a second series of assessments, the potential risk for the aquatic and terrestrial environment of the River Meuse and Scheldt from the actual releases (maxima and averages over the last ten years) was assessed. The more conservative ERICA assessments using maximum environmental media concentrations predicted with the Schaeffer river model, resulted in predicted dose rates of three orders of magnitude below the screening value of 10 µGy h^{-1}. Highest RQs were obtained for 'Insect larvae' (0.001) and 'Soil invertebrate, Detritivorous invertebrate, Rat' (0.003) for the Tihange freshwater and terrestrial ecosystems, respectively (Figure 2 A and B) with ^{60}Co the most contributing radionuclide. For Doel, highest RQs were obtained for 'Insect larvae' (0.003, ^{58}Co most contributing) and 'Shrub' (0.005, ^{137}Cs most contributing) for freshwater and terrestrial ecosystems, respectively (Figure 2 C and D). RQs for the more realistic predictions of environmental media concentrations, using the ten-year discharge averages, are a few-fold lower than those predicted for the release maxima. Actual liquid radiological discharges are hence considered to have no impact on the aquatic and terrestrial ecosystems of Meuse and Scheldt.

4. CONCLUSIONS

For the discharge limits (set to protect man), all RQs were below one. It could hence be concluded that the liquid radiological discharge limits for the Belgian NPP are set stringent enough to not harm the aquatic and terrestrial environment of Meuse and Scheldt. Since for the different radionuclides considered, actual discharges are up to 4 orders of magnitude lower than discharge limits, RQs



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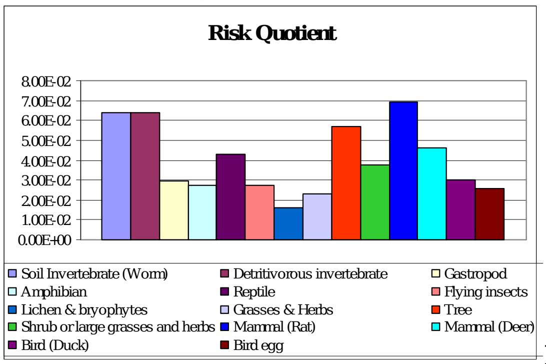

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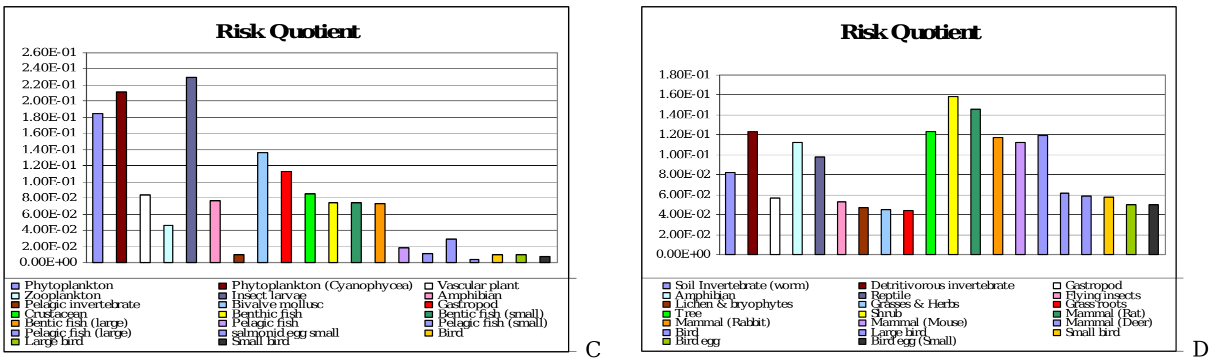

Figure 1 - Risk Quotients for selected reference organisms following a Tier 2 risk assessment for the Tihange (A, B) and Doel (C, D) liquid discharge limits for aquatic (A, C) and terrestrial ecosystems (B, D).

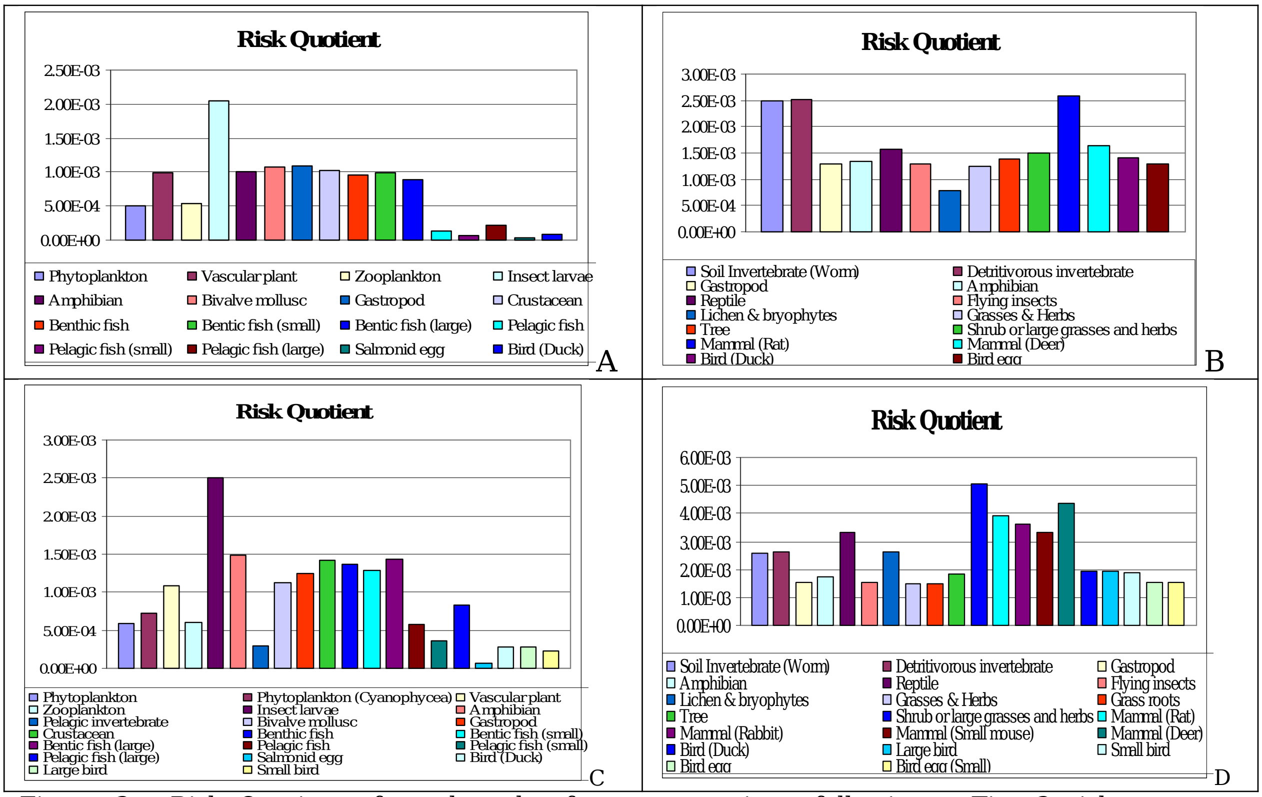

Figure 2 - Risk Quotients for selected reference organisms following a Tier 2 risk assessment for the Tihange (A, B) and Doel (C, D) actual discharge maxima (1999-2008) for aquatic (A, C) and terrestrial ecosystems (B, D).

obtained are <<1 and the freshwater and terrestrial environment of Meuse and Scheldt is expected not to be harmed by the actual liquid discharges from the Belgian NPP.

It should be noted that there is important uncertainty involved with the environmental transfer modeling and consequently the Environmental Risk Assessment performed. Assumptions concerning the source term composition were made. Furthermore, for many input parameters, in particular the concentration ratios, data are scarce or even unavailable and various methods were used to derive best estimate parameter values. However, for realistic (to some extent still conservative) assessment scenarios, the estimated dose rates

to freshwater and terrestrial organisms were three orders of magnitude below the screening value of 10 µGy h^{-1} at which the ecosystem is assumed not to be affected. Therefore, we can assume that it is very unlikely that the freshwater and terrestrial ecosystems of Scheldt and Meuse are affected by the liquid routine discharges from the Belgian NPP.

Acknowledgements
This study was performed on behalf of Gdf-Suez, under the Gdf-Suez/SCK•CEN agreement framework.

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